Benefits of modelling for the electroplating industry

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Introduction

Although one finds on the market suited software, simulation of electrochemical processes is not yet a common practice. Several reasons explain this situation.
First of all electrochemical processes are not so easy to understand and quantify than for instance mechanical properties. Before one can start reliable calculations, one has to put some effort in obtaining the bath properties and electrode reaction behaviour.
Secondly plating is not always considered as full part of the design of a work piece. Engineers make things in view of functional properties (strength, aesthetics, etc.) and then the plating industry has to realise the suited surface properties on it with fixed geometry.
A third problem is related with the fact that work pieces are often placed on a rack in a plating tank. This means that the geometrical configuration that one has to consider is not only the work piece but the whole plating environment with a large number of pieces.

These difficulties are no longer reasons for claiming that simulation, also called *dry running* or *virtual plating* is not worth to or cannot be implemented. There are on the contrary a lot of industrial situations where simulation offers considerable technical and economical benefits for plating processes.

First some essential background information is given: the theoretical concepts behind, the practical possibilities and limitations of these concepts, aspects of CAD integration with special attention to features being important for rack plating such as a random distribution of identical parts and contact problems, technical performances such as the size of problems which can be treated in practise, speed and accuracy of simulated results and future developments.

A second part covers applications and in a third part, the practical relevance of simulations is discussed. The technical and economical benefits of a cost-efficient design and manufacturing are highlighted.

Theoretical concepts

The applicability of simulations to electrochemical reactors is not straightforward due to the complexity of the processes that govern this kind of processes. In general, a complex interplay of the following phenomena can take place: electrochemical electrode kinetics, electrolyte hydrodynamics, ionic mass transport, gas evolution, and heat generation in the bulk and at the electrode-electrolyte interfaces. From a pragmatic point of view it is today not very realistic to consider all these phenomena simultaneously. From daily practice it is known that one has to assure a sufficient agitation and refreshment of the electrolyte. One also should avoid gas accumulation and large temperature variations. When these conditions are met, the so called Potential Model (PM) allows to predict the layer thickness distribution with already high precision. The PM is based on the following concepts.

The current density $\bar{J}$ in the electrolyte is given by ohms law in local form

$$\bar{J} = \sigma \bar{E} = -\sigma \bar{\nabla} \, U_{electrolyte} \qquad (1)$$

with σ the conductivity of the electrolyte, $\bar{E}$ the electric field and U the potential. By expressing conservation of current in each point one obtains the Laplace equation for the electrolyte potential U

$$\bar{\nabla}(\bar{J}) = \bar{\nabla}(-\sigma \bar{\nabla} \, U) = 0 \quad . \qquad (2)$$

On insulating boundaries, the current density perpendicular to the surface should be zero, which results in the following boundary condition:

$$\bar{J}.\bar{1}_n = J_n = -\sigma \bar{\nabla} U.\bar{1}_n = 0 \quad . \qquad (3)$$

On electrodes, it is known that the current density, which is proportional to the reaction speed, is a function of the so-called overpotential being the potential difference between in the electrode potential V and the electrolyte potential U (outside equilibrium). This relation can be quite complicated. In general one can write

$$J_{tot} = f(V - U - E_{otot}) \ , \tag{4}$$

with J_{tot} the total current density being the sum of all partial current densities. For a given metal Me deposition of removal one has to consider the current efficiency θ such that

$$J_{Me} = \theta(J_{tot})J_{tot} \tag{5}$$

For instance, in view of precise Cr plating one is obliged to measure the conductivity σ (S/m) of the electrolyte at processing temperature and the functions $J_{tot} = f(V - U - E_{otot})$ and $\theta(J)$ on anode and cathode.

The local removed or deposited thickness δ on an electrode is simply computed from Faraday's law:

$$\delta = \frac{M}{\rho z F}\theta(J)J_{tot}\Delta t \tag{6}$$

where M is the atomic weight of the metal, ρ is the density, z is the number of electrons exchanged in the metal reaction, and F is Faraday's constant.. Δt (s) is the process time.

One can criticize this simple Potential model but it is for sure the first step to be performed in virtual plating. Even in the best flow conditions, a bad current density distribution will provide uneven deposits. The Potential Model can also become very complicated when coupled with ohmic effects of resistive layers (e.g encountered in plating on plastics (POP)), contacted in distinct points.

The practical implementation

Simulation involves the availability of the geometry of the cell configuration in such a form that one can solve the physical model, in our case the Potential Model with its boundary conditions, on that geometry.
Several possibilities can be considered but the integration in an professional 3D CAD system offers a total flexibility of defining and changing the geometry. Referring to rack plating one can draw the plating tank with its anodes once and combine that geometry with changing racks and changing work pieces on racks. CAD drawings can be obtained from designers. Once available, they are copied, displaced, rotated etc. and distributed on a rack.
Based on these CAD drawings the specific aspects of a plating tank are defined: choosing the right bath, defining (sets of) electrodes and eventually contact points, define the applied current or potential (in total or per part) is all done an interactive way. In order to reduce the user interaction to a minimum, global parameters are set that enable to generate a suited grid of triangles that is needed to solve Laplace equation (2). In this approach particular attention is paid to reduce user interaction and to increase speed. For instance, the possibility to define master and slave work pieces reduces errors, memory and speed. The overall result makes it possible to simulate full industrial electrochemical processes with about 2 million unknowns in less than 30 minutes on a good standard PC. A typical example is given in figure 1 where the calculated chromium layer thickness is give on one part that was placed in the configuration given in figure 2.

Fig. 1: Simulated Cr deposit layer thickness on a single part

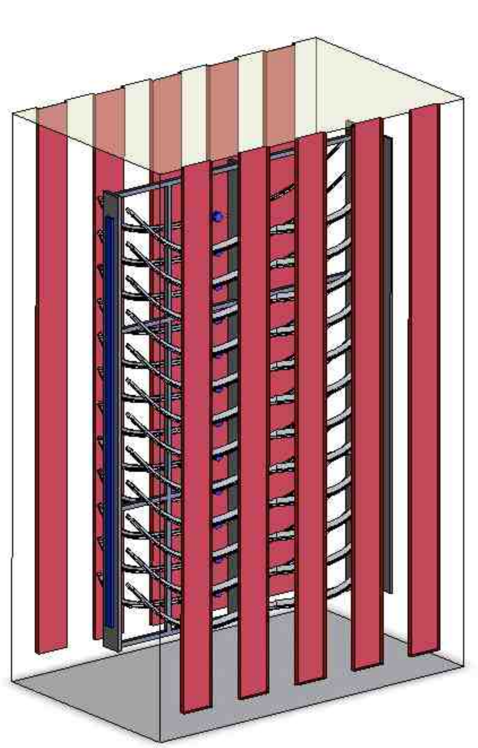

Fig. 2: CAD configuration of plating tank (partly) with rack of parts and current robbers

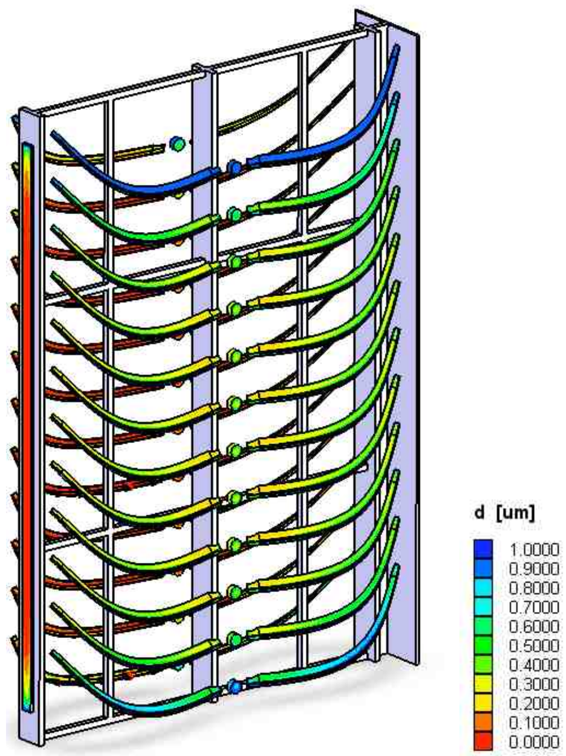

Fig. 3: Simulated Cr deposit layer thickness

In figure 3 the global plating result on all parts is shown. Clearly one can start improving the situation in a quantified and technically justified way. One can add screens and electrodes, modify positions, change applied current or potential, etc. .

One can say that nowadays any practical problem can be simulated. Applications are found on any scale going from wafer or PCB plating, reel-tot-reel plating, single or multiple part plating to very large scale where complete dashboard or air wing moulds are electroformed The accuracy one can reach depends on the process that is considered. In general one can reach 90 % and in any case all trends indicated by a dry run is also seen in reality.

Starting from a first current density distribution, the given efficiency and time step, it is possible to calculate the material deposit of removal. In electroforming (EF) or electrochemical machining (ECM) applications the electrode shape changes are so large that one is forced to continue the calculation in several steps. Between two consecutive steps the geometry is adapted automatically to the new electrode shape. Also here full CAD integration offers solutions to practical problems. A lot of expensive testing is eliminated by fast and cheap simulations. The modified electrode shapes are reconstructed to real CAD entities that become an integral part of the CAD-model. In this way it is possible to perform e.g. a stress analysis on a work piece that has been made by ECM or EF. An example is given if figure 4.

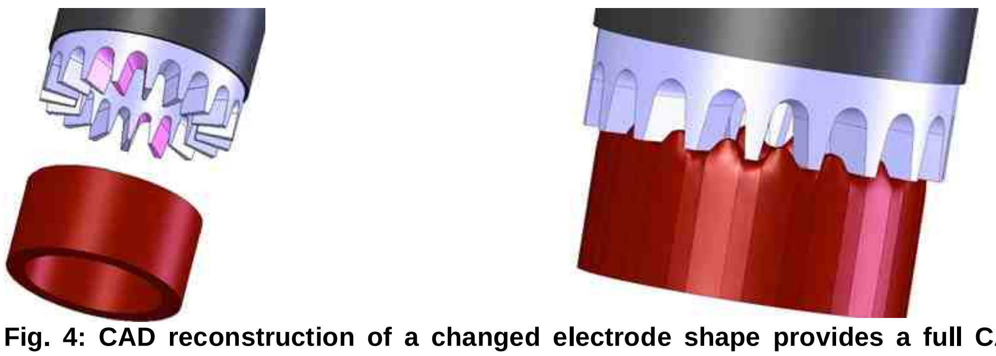

Fig. 4: CAD reconstruction of a changed electrode shape provides a full CAD model of the modified work piece.

Further development of virtual plating tools will go in the direction indicated by the users. Trends are:

- automated optimisation of geometrical configurations and process parameters,
- simulations will be completed with more pre- and post-processing of the results such that they provide more production relevant data and become part of the production flow (cost calculation, energy, material consumption, etc.),
- integration with measured data and quality control,
- integration with Computer Automated Manufacturing (CAM) tools.

Benefits

Benefits can be pure technical, economical or mixed. They are evidently in relation to the products that are to be made. Nuts and bolts need no simulation but many parts in automotive, aeronautic, medical, domestic appliances, electric and electronic industry with high added value and/or high mass production and/or increasing complexity need to be taken into consideration.
By doing simulations one can maximise and optimise single part cells up to complete rack configurations. The direct benefits are:

- Reduced material usage,
- Increase of bath utilisation,
- Increased conformance per batch,
- Increased yield per batch,
- Mixed component batches,
- Shortened lead times (trial and error wet runs)
- Reduced number of process steps, leading to,
    - reducing manipulation and labour requirements,
    - reduced interim treatments,
- Reduced plating time,
- Reduced post-processing and rework.

In addition to that, new configurations (reactors or racks) are designed much faster with less trial and error. One can argue that skilled electroplaters have all the know-how to this. Indeed they do but the difference is that when a skilled electroplater is working with a tool that provides quantified results, one can go far beyond standard practise in a *quantified* way and test all ideas by virtual plating, including fine tuning down to an accuracy that allows much higher spec's than achievable by standard practise. The whole plating process is understood better, the problems are seen, quantified and solved in advance. The knowledge is no longer intuitive. This reduces the number of wet run trials from several ones to two, one or even zero (first time right) in many cases. It leads to more production potential, confidence, stability, reproducibility and saves manpower costs. Figures 5 and 6 show an example of electroforming of a mould for making dashboards. Figure 5 shows the complex geometry with on the right some screens and additional anodes.

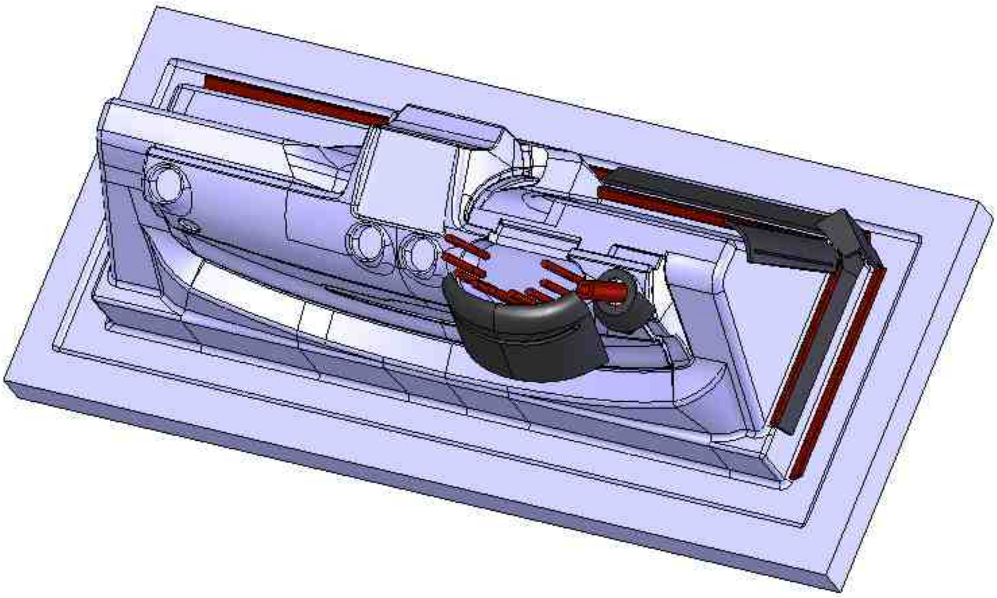

Fig. 5: CAD view of a dashboard to be plated for several days in order to make a mould.

A uniform growth is certainly not guaranteed and several steps are needed to make a final mould with a thickness of a few centimetre. The number of these steps is much reduced by simulation. This is shown in figure 6.

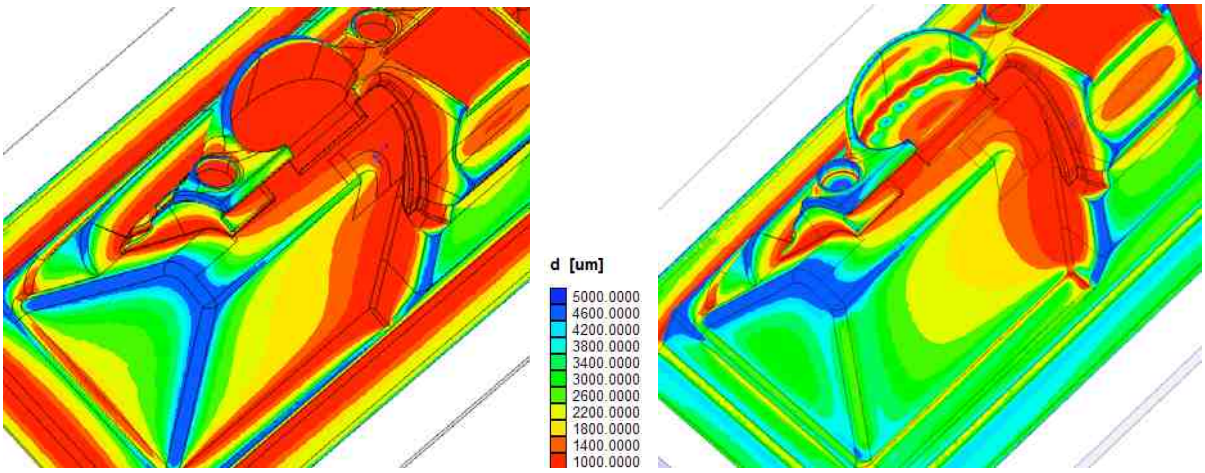

Fig. 6: Deposit thickness distribution over the mould for a situation without auxiliary screen and anode structure (left) and with this structure (right)

The ability to provide accurate quotations increases customer confidence and wins more business. In very complicated situations one can explain the customer that the technical limits of manufacturing are reached. Real huge global cost reductions can be realised when also work pieces are (to some extent) redesigned in mutual agreement with the customer in view of plating requirements.

It is very useful to make a ROI study on all in house plated products. Answers to the following questions need to be given:

- What is the cost of refusing an order because it was judged to have too tight spec's? or the other way around: judged too simple and quoted too low?
- what is the cost and lead-time (set-up, test runs, measurements, modifications, ..) for putting a new work piece into production? What can be saved if that cost is reduced with 50 to 80 %?,
- what is the cost reduction of putting 5 to 20 % less metal while maintaining within specifications?
- what if on has in global 5 % less scrap (rejected parts)?
- what are the savings of producing in the same time a given number of work pieces more? Or to put it differently: what is saved with an enhanced capacity of the existing production lines?
- what if one can reduce with 50% or eliminate post-processing? Suppose that one can save 50 % in a subsequent milling step.
- what is the cost of parts that need to be reworked?
- What can be saved if a new concept is tested virtually before it is really implemented?

Quantified answers to these questions can be given by virtual electrochemical processing. Clearly, the ROI or business cases are specific to a defined industrial setting. However, based upon industrial experiences, we have seen that for decorative finishing rack plating applications , a positive ROI of 50 k€ due to scrap reduction for one single part / year is no exception. For gold and platinum plating applications, ROI's mounting above 250 k€ / year are more the rule than the exception. For electroforming application, a combination of reduced manpower for reworking and material savings can also mount to above 100 k€ for one single model. In general, reductions in lead time and related manpower for ECM applications shows ROI's above 25 k€ for one single application. And these figures do not include the other above-mentioned strategic long-term advantages.

How to start with simulations

It is clear that some effort is needed to make simulation part of the production philosophy. It also takes time but it can be implemented stepwise. Best is to choose a given work-piece for a first internal evaluation. This can be done in collaboration with the software provider as follows:

- In a meeting any key plating processes/components are identified where there is margin for improvement offering substantial payback potential (ROI),

- A number of computer simulations is carried out to design an optimised plating arrangement and operating conditions,
- The results are presented in a subsequent meeting and together a business case for process optimisation is drawn up,
- The improvements are realised and measurements are compared with simulations,
- A ROI is calculated and conclusions are drawn.

In this way, it is rather easy to show what is possible and the customer can judge the value of simulations. At this stage the customer needs not to take care of any practical aspect of simulations. Depending on the outcome and the applications, on can proceed in different ways. Other cases can be analysed and optimised in the same way or stepwise the technology for in-house simulation is transferred. One might also consider intermediate steps where part of the work is done by the user and part by the software provider.

Conclusions

Simulation of electrochemical processes is now available at full industrial level. It provides substantial improvement and cost reduction to high quality and high volume electroplating in all kind of industrial applications.
The implementation of this new way of working and new way of approaching electroplating needs some effort and time. It is without any doubt that virtual plating will become part of daily practise in the very near future.

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